A Proposed Curriculum for Nuclear Power Engineering, Curriculum 572, for U.S. Navy Civil Engineer Corps Officers

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A Proposed Curriculum for Nuclear Power Engineering, Curriculum 572, for U.S. Navy Civil Engineer Corps Officers

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I. INTRODUCTION

During the last four years, U.S. Navy Civil Engineers Corps (CEC) Officers selected for postgraduate education in Nuclear Power Engineering Curriculum 572 have elected to pursue their course of study at The Pennsylvania State University (PSU). The course of instruction and research facilities available at this institution have, to date, satisfied the educational requirements for officers serving in the Naval Facilities Engineering Command Nuclear Shore Power Program to the degree that PSU is now the only insitution listed in the annual NAVFACNOTICE for Curriculum 572.[1]

As in any rapidly advancing technological field, the educational institution is hard-pressed to keep up with the latest important developments in its field. In addition to this problem, the Nuclear Engineering Department at PSU finds that the undergraduate work and experience of its graduate students vary greatly. Only a small percentage of each new graduate class has completed undergraduate work in nuclear engineering; the national output being only about two hundred per year.[2] This percentage is expected to increase in the near future with the initiation of an undergraduate Nuclear Engineering Curriculum at PSU in the Fall of 1968. On the other hand, the Atomic Energy Commission (AEC) trainees and Navy trained students (other than CEC) have excellent nuclear backgrounds in most cases, but this will change in that the naval officers will not have previous Navy training in nuclear power commencing with entrants in the fall of 1970. This decision was probably based on the fact that these officers are satisfactorily prepared for their future billets through completion of the Navy Nuclear Power Schools'

curriculum. Thus in the future, it appears that students without nuclear education on the BS level will be required to schedule more courses that are becoming part of the undergraduate program than were previously scheduled by graduate students in the past. Considering the rapidly moving situation, ie, some increase in graduate students with a BS in Nuclear Engineering, that now exists in the Nuclear Engineering Department, it becomes apparent that the ideal curriculum of 1968-69 or 1969-70 will, in all probability, require revision three or four years hence.

The first objective of this paper is to identify specific learning objectives (Section III) to be satisfied by the curriculum from the known areas of responsibility of major billets in the Navy Nuclear Power Unit currently held by PSU graduates and from the author's experience. The second objective is to determine how the specified learning objectives can be satisfied through scheduling of current courses (Section IV) and participation in the Reactor Operator Training (Section V) and Supervisor Training (Section VI) programs. As part of this objective, the Supervisor Training Program will be discussed in detail and proposals concerning additions will be presented. The third objective of this paper is to present the education and training programs offered by private industries prominent in the nuclear reactor field and the curriculum offered by the Navy Nuclear Power Schools (Section VII) for the purpose of comparing these programs to the proposed curriculum. The fourth objective addresses the subject of candidate selection (Section VIII) since student motivation, as well as previous education and training, is clearly an important factor in the learning process, especially in a highly technical field of endeavor such as nuclear engineering. The subject of selection of an educational institution which is capable of administering the proposed

curriculum is also discussed. Finally, the fifth objective is to present the proposed curriculum (Section IX), including the two training programs, which will satisfy the learning objectives, hopefully meet the education objectives of the Nuclear Engineering Department at PSU, and allow the candidate to obtain a Masters Degree in the allotted eighteen months.

As was noted above, none of the future naval officers entering PSU in the Nuclear Engineering Department will have had Navy Nuclear Power Training, therefore the curriculum proposed in this paper should be applicable to Navy Engineering Duty Officers (EDO) as a course of study under Nuclear Power Engineering (ED) Curriculum 520. Even though the missions and tasks of this particular Corps, such as, shipboard nuclear reactor propulsion system design, repair, and operation, differ from those promulgated for the Naval Nuclear Power Unit, Fort Belvoir, Virginia, the general learning objectives readily apply.

II. POSTGRADUATION OFFICER ASSIGNMENTS

Current policy dictates that all officers completing Curriculum #572 will be assigned to the Navy Nuclear Power Unit, Fort Belvoir, Virginia. This unit is responsible to provide such services to its parent command, the Naval Facilities Engineering Command, as design, procurement, construction, operation, maintenance, support and modification on Nuclear Shore Systems; to coordinate with other services in the joint staffing of Nuclear Shore Systems; to coordinate the personnel procurement and training for supporting Nuclear Shore Systems; and to administer naval personnel in training for nuclear qualifications or assigned to operate and maintain operational or training Nuclear Shore System Facilities of the Navy or of other services.[3] Generally, the first assignment after completion of graduate school would not involve all of the above mentioned areas of responsibility, but it could encompass more than one of these functions. In order to fulfill any of these areas with any degree of competence, the officer must have a good background in nuclear engineering attained through formal education and/or practical experience.

Two billets which are currently filled by officers who have recently graduated from PSU with a Masters Degree in Nuclear Engineering are that of Plans and Operations Officer, U.S. Naval Nuclear Power Unit, Fort Belvoir and Officer-in-Charge, U.S. Naval Nuclear Power Unit Detachment, McMurdo Station, Antarctica. The responsibilities and functions of these assignments will be reviewed below in order to determine which areas of knowledge in the nuclear engineering field are of immediate concern and should be included in the curriculum.

A. The Plans and Operations Officer

The Plans and Operations Officer is responsible to the Officer-in-Charge for support of the PM-3A Nuclear Power Plant and as the Unit's Program Coordinator for the Nuclear Shore Power Plants Program within the area of Naval Nuclear Power Unit responsibility. In discharging these responsibilities, some of the major function areas involved are monitoring the operation of the PM-3A Nuclear Power Plant; providing or coordinating all required plant support, both logistic and engineering; planning and preparation of approved work projects including material procurement, contracts specification preparation and administration of procurement contracts; controlling all radioactive materials shipments including arranging permits, complete documentation, transportation, special handling, processing, and disposal; preparing special operating and maintenance procedures for technical manuals and/or special projects; providing health physics and control support in the form of data processing and evaluation, maintenance of health physics equipment allowance list, resolution of technical problems and review of routine plant operations; reviewing and evaluating environmental monitoring data in connection with nuclear power plant operations; performing technical review and evaluation of technical reports prepared by support contractors or other engineering offices; and exercising budget, commitment and obligation control over those funds designated for support of Nuclear Shore Power Plants.[3]

B. The Officer-in-Charge, U.S. Naval Nuclear Power Unit Detachment, McMurdo Station, Antarctica.

The mission of this detachment is "...to provide the primary source of electrical power and fresh water for McMurdo Station from the PM-3A

Nuclear Power Plant and the Water Distillation Plant; to operate, maintain and modify the PM-3A and the Water Distillation Plant and to provide technical assistance in support of associated equipment; to test and evaluate the concept of a portable, nuclear power plant in an isolated, hostile environment; and to provide a base of trained and experienced personnel for the Navy Nuclear Shore Power Program".[3] This officer is responsible to the Officer-in-Charge, Navy Nuclear Shore Power Unit for carrying out the above described mission. In addition to these functions he is assigned collateral duty as Commander, Antarctica Support Activities Radiological Protection Officer and he reports to the Atomic Energy Commission, New York Operations Office Manager for additional duty as AEC Representative, Anarctica, in connection with the accountability, custody and reporting for special nuclear material.[3] The importance of these collateral duties can not be overemphasized since this officer must act on matters concerning radiological safety and special nuclear material in an area of international activity and under conditions which preclude on-site consultant services during the winter period. In discharging these responsibilities, some of the major function areas involved are to supervise and coordinate the work effort of assigned personnel and exercise management control over assigned resourses; to provide safe, reliable operation, maintenance and modification of the PM-3A and Water Distillation Plant; to operate an environmental surveillance program for McMurdo Station; to assure the radiological safety of all personnel entering or working in the plant area; to establish effective preventative maintenance and maintenance programs for all equipment in the PM-3A complex; to prepare and exercise the PM-3A Emergency Plan for nuclear incidents, fire or disasters involving the PM-3A including emergency recovery and monitoring equipment; and to

conduct programs for the training, qualification and certification of PM-3A and distillation plant personnel.[3]

Considering the missions of the Naval Nuclear Power Unit and the detachment at McMurdo Station and the responsibilities and major function areas of the two billets described above, it is now practical to compile a list of general "end-product" knowledge areas or learning objectives which should be satisfied through the formal education and training program at PSU.

III. LEARNING OBJECTIVES

During a meeting in November 1968, between the Officer-in-Charge, U.S. Naval Nuclear Power Unit, Fort Belvoir and the Head, Nuclear Engineering Department, The Pennsylvania State University, a list of "end-product" knowledge factor was presented. The following list of learning objectives is an amended version of the original general topic listing presented by the Officer-in-Charge. The detailed subject areas to be covered in each general topic were determined by the author from his personal experience.

1. Fluid Flow - Study of basic thermodynamic and dynamic principles applied to fluid behavior; turbulent flow inside pipes and through tube bundles; typical pressurized water reactor piping diagrams, primary and secondary loops; types and purpose of values and pumps in reactor systems; discussion of operating problems encountered in pumps, seals, and piping in PWR's.

2. Heat Transfer - Modes of heat transfer; thermal conductivity; surface heat transfer coefficient; thermal boundry layer; equations of conduction; composite walls; over-all coefficient of heat transfer; critical radius of insulation; fins; heat transfer equations in turbulent flow; analysis of heat transfer in turbulent flow using the Momentum-Heat Transfer Analogy; experimental results of Reynolds and Martinelli and for forced-convection, turbulent flow in tubes; heat transfer with boiling; study of heat exchangers including overall heat transfer coefficient, fouling factors, temperature distribution, NTU design method, prescribed heat

flux distribution, and heat exchanger design.

3. Basic Electronics - Introduction to electronics; study of the amplifier including amplification, cascaded stages, input and output impedance, gain, and effects of source voltage, source resistance and load; introductions to vacuum tubes and the vacuum diode; study of triode, tetrode, and pentode amplifiers; semiconductors and the semiconductor diode; transistors; transistor switching circuits and multivibrators; DC power supply; application to reactor plant instruments.

4. Atomic and Nuclear Physics - Special theory of relativity; particle properties of waves; wave properties of particles; atomic structure; the Bohr model of the atom; quantum mechanics; the quantum theory of the hydrogen atom; electron spin and complex atoms; the atomic nucleus; natural radioactivity and the laws of radioactive decay; nuclear reactions; attenuation theory.

5. Nuclear Instrumentation - Purpose of instrumentation and current philosophy; operating characteristics and specification of gas-filled detectors, ionization, and compensated ionization chambers; the channel approach to neutron flux range coverage; transmission line theory; general classes of preamplifiers and their operating characteristics; pulse shaping; evolution of detectors, circuits and component arrangements for detection of neutron fluxes in the various channels, including cambelling; early work in reliability; basic reliability principles and sample calculations; redundancy; computer systems for checking instrumentation system; various testing schemes; logic circuits.

6. Feedback Control Systems - Open and closed loop control systems; loop analysis using differential equations and transfer function approaches; Laplace transform; stability definitions; Nyquist, Root-locus, Bode, and Nichols chart analysis; solutions of kinetic equations for step, ramp and sinusoidal function input in δk by determining reactor transfer function; reactor transfer function with temperature coefficient and poisoning feedback loops; reactor automatic-control system; control loop response; steady-state programming; applications and limitations of temperature loop transfer functions; temperature coefficient reactivity feedback loop; transient analysis; automatic plant control.

7. Digital Computers - General description and functional units; machine language and assembly, translating and operating systems; FORTRAN translating system and programming procedure; statements; input and output statements; arithmetic assignment statements and sample programs; types of values; program control; arrays; subprograms; programming practical problems.

8. Analog Computers - Introduction to electronic differential analyzers; basic computing elements; programming ordinary and simultaneous differential equations and differential equations excited by a forcing function and its derivatives; time and magnitude scale factor selection and use; direct integration of nonlinear differential equations; computer operation and operational considerations; formulation of a problem for simulation; programming and scaling of simulator problems; nonlinear function generation; simulation of nonlinear systems; solution of practical problems.

9. Reactor Theory - Nuclear structure and stability; interaction of neutrons with matter including discussion of cross sections and scattering; nuclear fission; nuclear chain reactions; monoenergetic neutron diffusion; neutron moderation without absorption; neutron moderation with absorption and fission; low-energy neutrons; Fermi Age theory; multiregion reactor with reflector - group diffusion method; heterogeneous reactors; reactor kinetics; changes in reactivity; control rods.

10. Power Plant Theory - Thermodynamic aspects of nuclear power; reactor heat generation and removal; reactor coolants; heat transfer and fluid flow with change in phase; pressurized-water reactors and power plants; typical primary and secondary main coolant systems; pressurizer performance and control; steam generator design and operation; steam turbine design and operation.

11. Radiochemistry - Radiation detection and measurement; use and familiarization of instruments used in radiation detection; statistical consideration in radioactivity measurements; determinate corrections in radiation measurements; use and familiarization of scintillation detectors.

12. Reactor Materials - Basic elements of physical metallurgy; strength of materials and types of failures; methods of metal forming and joining; materials irradiation; corrosion of materials; cladding materials; fuel materials; poison and control materials; fuel element fabrication; plant structural materials and component fabrication; inspection, quality control, and standards; thermoelectric materials in radioisotope thermal generators and possible irradiation damage.

13. Dynamic Behavior of Reactors and Power Plants - Study of the interplay of core and plant temperatures including the derivation and use of hot channel factors; determination of maximum fuel temperatures and DNB ratios; analysis of reactor transients; lifetime behavior of reactivity; local power peaking; transient thermal performance; thermal and hydraulic performance during complete loss of coolant flow accident (CLOFA).

14. Safety Analysis - Study of various types of accidents, such as, cold water accident, steamline break, CLOFA, etc.; reactor site criteria including distance factors for power reactors for abnormal radioactive releases; engineered safety features including general requirements, various containment designs, containment pressure and temperature reducing systems, emergency core cooling systems, air cleanup systems, and dispersion systems.

15. Licensing of Reactors - Procedure to obtain license to operate a nuclear reactor; siting criteria including considerations in topography, access, land use, population distribution, hydrology, seismology, meteorology, and release of plant effluents; typical items included in a Preliminary Safety Analysis Report (PSAR); problems related to obtaining public consent for nuclear plant construction with case histories.

16. Radiation Shipments - Interstate Commerce Commission Regulations; AEC requirements (10 CFR 71); grouping of radioactive materials; exemptions; construction and size of containers; maximum dose rates.

17. Health Physics - Introduction and definitions of terms; detection and monitoring devices; types of radiation and their properties; principles of exposure control; biological effects of radiation including emergency limits, equivalent residual dose, radiosensitivity of cells in tissue, and effects of various dose levels; types of surveys; decontamination procedures.

18. Standard Reactor Tests - Test procedures, performance, and evaluation of results are accomplished utilizing laboratory experiment techniques. The tests include determination of rod worths, excess reactivity measurement, effects of temperature coefficient, observation of the Xenon phenomenon, determination of critical mass, and performance of power reactor instrumentation.

19. Fuel Management - General survey of fuel management practices including the fuel cycle, in-core fuel management, intrinsic value of spent fuel, fabrication, enrichment, and reprocessing.

20. Operator Qualification - Standard reactor operating procedures; pulse characteristics; reactivity and poisoning calculations; physical characteristics of the plant; technical specifications; rod drive mechanisms; servo systems; safety analysis; reactor operation including instrumentation and monitoring checkout, experience in reactor start up to criticality, operation of reactor including power changes, experience in reactor shutdown, and observation of various reactor operations.

Where the preceding objectives apply to reactors it would be desirable to have problems on or applications to low enrichment, pressurized water reactors. Familiarization with other types of reactors, coolants and fuels would be beneficial.

These objectives can be satisfied in a variety of ways; foremost of which is formal instruction through current courses. Reactor Operator Training at the PSU Nuclear Reactor Facility fulfills several other objectives and offers some duplication of material offered in formal course work, which is desirable since it is presented from the technician's viewpoint. This program is offered in the fall and winter terms. Supervisor Training is currently flexible enough to allow for completion of the remaining objectives. A proposal for satisfying these remaining objectives is presented later in this paper. In order to determine which objectives must be covered in this program, we must first determine which objectives are satisfied by current courses and Reactor Operator Training.

IV. LEARNING OBJECTIVES SATISFIED BY CURRENT COURSES

The current courses shown in the following listing include preparatory courses in addition to those courses which satisfy the learning objectives. The listing is presented by term and unless otherwise noted, the courses are available for the term listed according to the 1969 schedules and any other advance scheduling data available.[4] It should be noted that the course descriptions are brief and general in nature due to the fact that specific course content in many instances changes from year to year to accommodate a rapidly developing field. These current courses must accomplish the general areas indicated and therefore satisfy the learning objectives previously mentioned which were purposely defined in brief, general terms. Furthermore, only approved courses which can be practically scheduled in the allotted eighteen months are included. It should be noted that a full-time graduate student must schedule a minimum of eight credits but no more than ten credits. Graduate credits for the courses listed below are shown in parenthesis - zero indicating an undergraduate level course.

A. First Summer Term

1. Mathematics: A good working knowledge of ordinary and partial differential equations is required in order to grasp the fundamental concepts of nuclear reactor theory presented in the following terms. Based on the fact that most candidates received their undergraduate degree four to six years prior to entering graduate school and little use of differential equations is required in filling junior officer billets in the Civil

Engineer Corps, an undergraduate level differential equations course should be scheduled during this first term. A more advanced differential equations course would be an appropriate elective in the following terms as would formal instruction in probability and statistics theory.

a. Math 100 - Differential Equations (0). First order differential equations; second order linear equations; series solution of second order linear equations; higher order linear equations; Laplace transforms.

b. Math 431 - Ordinary Differential Equations (3). "Linear ordinary differential equations; existence and uniqueness questions; series solutions; special functions; eigenvalue problems; Laplace transforms; additional topics and applications".[5]

c. Math 409 - Introduction to Mathematical Statistics (3). Distribution of random variables; conditional probability and stochastic independence; special distributions; distributions of functions of random variables.

2. Physics: The comments under Section IV.A.1. are also pertinent to the fundamental concepts of Atomic and Nuclear Physics which is listed as a learning objective. The undergraduate course is considered to be the appropriate level of instruction based on the fact that most candidates have an engineering vice science background. The second course listed should be scheduled only by those candidates with more physics background than that obtained by the average engineering undergraduate.

a. Phys 237 - Introduction to Atomic and Nuclear Physics (0). Atomic and molecular theory, realistic kinematics and dynamics; quantum effects; structure of the Atom; nuclear structure and reactions.

b. Phys 454 - Atomic and Nuclear Physics (3). "Introduction to experimental evidence and theories of atomic and nuclear physics and electromagnetic radiation".[5]

3. Nuclear Engineering: As was discussed earlier, it is expected that in the near future, candidates will have little grounding in nuclear engineering. It is therefore necessary to obtain the basic fundamentals of the effects of ionizing radiation and its associated hazards (learning objective) as soon as possible. Also a knowledge of the basic concepts of the nuclear properties of matter and of nuclear engineering itself would be helpful prior to scheduling in-depth nuclear engineering courses. The below listed courses are suggested for this first term in order of descending value based on the learning objectives, past history of course offerings by this department, and the author's personal experience.

a. Nuc E 400 - Nuclear Engineering Special Topics (1-12). "Individual or group studies in some area of nuclear engineering".[5] May be tailored to include parts of material offered in Nuc E 401 and Nuc E 405.

b. Nuc E 420 - Radiological Safety (2). "Ionizing radiation, biological effects, radiation measurement, dose computational techniques, local and federal regulations, and exposure control".[5]

c. Nuc E 405[a] - Nuclear and Atomic Properties of Matter (3). "Particle interaction kinematics and dynamics; nuclear and atomic energy transitions; interactions of photons, electrons, neutrons, and ions with matter".[5]

[a] Currently not offered during summer term.

d. Nuc E 401[b] - Introduction to Nuclear Engineering (3). "Fundamental concepts of Nuclear Engineering, including fission, reactor theory, shielding, and radioisotopes...".[5]

e. Nuc E 407 - Statistical and Transport Descriptions of Matter (3). "Many-body problems; statistical mechanics; transport-like descriptions of matter, energy, momentum, mass transfer, esp. analysis of low density particle distributions".[5]

4. Computer Science: "The Institutional Study Committees report that it is essential for the engineer to have a knowledge of digital computers so that he may know what problems may best be solved on the computer and may be able, himself, to use the computer and direct others in doing so. The need is stressed for educational experience which will enable the engineer to meet the rapid changes in technology and language that will be evolved rather than for knowledge of present techniques. Engineering already has been significantly affected by the use of digital computers, but even more profound and far-reaching changes are to be expected in the future".[6] Scheduling a basic digital computer course during this term satisfies the learning objective.

a. CMP SC 401 - Principles of Programming with Physical Science Applications (3). "Structure of computer programs; algorithmic procedures; programming in artificial languages".[5] Generally eight to ten programs are developed and run.

B. First Fall Term

1. Nuclear Engineering: During the term, two of the listed learning

[b] Currently not offered during summer term.

objectives can be satisfied. They are reactor theory, in part, and radiochemistry - statistics, counting, familiarization with instruments. Starting in the fall term of 1969 and winter term of 1970, Nuclear Engineering Laboratory, Nuc E 440-441 will be offered. While the current course content is not applicable to a learning objective, future development of these laboratory courses may make their inclusion in this curriculum desirable.

a. Nuc E 410 - Nuclear Engineering (3). Review of nuclear physics; interaction of neutrons with matter; nuclear fission; neutron chain-reacting systems; the diffusion of neutrons; neutron moderation without absorption; neutron moderation with absorption and fission; low-energy neutrons; Fermi theory of the bare thermal reactor.[7]

b. Nuc E 502A - Reactor Engineering Laboratory (1). Five experiments are completed during this first in a series of three 502 laboratory courses. The experiments are Characteristics of Gas Ionization Detectors, Health Physics Measurements, Studying the Statistical Nature of Radioactivity, Determinate Corrections in Radiation Measurements and Scintillation Detector Experiment.

2. Mechanical Engineering: Again two objectives can be satisfied in this field of study - heat transfer and power plant theory, in part. The following courses have, in the past, been only offered during the fall term. If possible the heat transfer course should be scheduled for the first fall semester and the power plant course for the second fall semester.

a. M.E. 412 - Heat Transfer (3). "Heat, mass and momentum transfer are shown to exhibit similarity through their governing relationships. The application of the derived and experimentally obtained results

for heat transfer in typical industrial situations is the intended end result of the special areas of study which include: transient heat conduction; convection in laminar and turbulent flow for internal and external flow systems; change of phase through boiling and condensation; and thermal radiation. The course presents an orientation toward heat transfer phenomenum which can be utilized in the design of systems in which heat, mass and momentum transfer occur".[8]

b. M.E. 410 - Power Plants (3). "Thermodynamic and economic principles in cycle selection and adaptation; essentials of fuel-burning, hydro, and nuclear power plant constitution".[5]

3. Mathematics: The suggested follow-on course, Math 431, described in section IV.A.1.b. is generally offered in the fall and is considered an excellent elective in the event that M.E. 412 could not be scheduled.

C. Winter Term

1. Nuclear Engineering: The second of a two part course in reactor theory including some basic core design is offered. In addition, the second of a series of three laboratory courses and the first in a new series of two courses in design principles of reactor systems are scheduled. All of these courses should be considered required courses.

a. Nuc E 411 - Nuclear Engineering (3). Multiregion reactors - the group diffusion method; heterogeneous reactors; reactor kinetics; changes in reactivity; control rods; perturbation theory.[7]

b. Nuc E 502B - Reactor Engineering Laboratory (1). Five experiments are completed during this second in a series of three 502 laboratory courses. The experiments are Diffusion Length in Graphite,

Diffusion Length in Water, Age in Graphite, Exponential Experiment, and Critical Mass.

c. Nuc E 430 - Design Principles of Reactor Systems (3). Nuclear power cycles; reactor heat generation and removal; kinetic behavior of nuclear systems; materials and structural design problems.

D. Spring Term

1. Nuclear Engineering: During this term the objective concerning the dynamic behavior of reactors and power plants can be satisfied by either one of the first two courses listed below. Nuc E 431, which is being offered for the first time in the spring term of 1970, is slanted toward fundamental theory and concepts while Nuc E 501 will take a more rigorous analytical approach into the design principles of reactor engineering. The feedback control systems objective is satisfied by the course listed third below. Also the last of the series of three laboratory courses is offered.

a. Nuc E 431 - Design Principles of Reactor Systems (3). Economics of nuclear systems including fuel cycle, capital costs, fossil fuel comparison, reactivity balances; engineered safeguards; licensing; siting; field trip.

b. Nuc E 501 - Reactor Engineering (3). Review of steady state energy removal; hot channel factors; flow boiling crisis; reactivity requirements; power plant design; loss of flow accidents; reactivity insertions; siting; engineered safeguard systems; economics.

c. Nuc E 505 - Reactor Control (3). Elementary servomechanisms; use of Laplace transform; reactor kinetics; the reactor as a control element; automatic reactor control; and reactor control mechanisms.

d. Nuc E 502C - Reactor Engineering Laboratory (1). Five experiments are completed during this last in a series of three 502 laboratory courses. The experiments are Reactor Transient Rod Calibration by the Inhour Method, Measurement of Gamma Dose Rate from an Operating Reactor, Oscillator Measurement of β/ℓ^*, Study of Reactor Noise, and Determination of Nuclear Parameters Using a Pulsed Neutron Source.

2. Electrical Engineering: Since the use of analog and hybrid computers is growing in the nuclear power field, especially their use as simulators, a knowledge of the use and capability of an analog computer is set forth as a learning objective.

a. EE 470 - Electronic Analog Computers (3). "Basic principles of analog computation, including linear and nonlinear differential equations, linear partial differential equations", and laboratory problem solving.[5]

E. Second Summer Term

1. Nuclear Engineering: In addition to the first two courses listed below, which comprise the current Supervisors Training Program, a course in reactor instrumentation is offered. During this term considerable effort should be made toward writing and completing the engineering paper or thesis required for graduation.

a. Nuc E 502D - Reactor Engineering Laboratory (2). Setting up equipment, scheduling, performing and analyzing results for three experiments. The experiments are the Power Reactor Instrumentation Experiment, Excess Reactivity Measurements and Fuel Accountability, and Xenon Transient Investigation.

b. Nuc E 550Q - Power Reactor Safeguards and Operational Analyses (2). Since this course is currently under development and was designed to address those objectives not covered in other courses, a detailed proposal of course content is developed in this paper.

c. Nuc E 550N - Reactor Instrumentation (2). Use, operation, placement and specifications of various types of instrumentation required for safe operation of a power reactor. An individual project requires development of specifications for instrumentation of a nuclear reactor.

F. Second Fall Term

1. Nuclear Engineering: Course offerings in reactor materials and radiation shielding are generally available during this term. The materials course satisfies one of the listed learning objects and the shielding course offers an excellent opportunity for intense study in a specific area related to health physics.

a. Nuc E 511 - Nuclear Reactor Materials (3). "Philosophy, selection, technology, use, economics, and performance of materials of major interest in nuclear power reactors today".[9]

b. Nuc E 508 - Radiation Shielding (2). "Radiation sources in reactor systems; attenuation of gamma rays and neutrons; deep penetration theories; Monte Carlo Methods".[9]

In summary, the various approved courses satisfy thirteen of the twenty learning objectives excluding those objectives partially fulfilled by two courses listed as part of the Supervisors Training Program which is still in a developmental stage. Also excluded is Safety Analysis which should be considered partially fulfilled by Nuc E 431 or Nuc E 501.

Thus, seven objectives remain unsatisfied with two avenues of study open for their fulfillment - Reactor Operator Training and Supervisor Training.

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V. LEARNING OBJECTIVES SATISFIED BY REACTOR OPERATOR TRAINING

Reactor Operator Training (ROT) is divided into three distinct areas of instruction; operating the reactor, observation of reactor operations and classroom lectures. The primary objective of this program is to qualify operators for the PSU research reactor, therefore the entire program is tailored to meet this goal.

A. Operating the Reactor

Each trainee is scheduled for a minimum of two hours of operation per week. This time is always scheduled in the morning so that the trainee becomes proficient in the checkout of the reactor instrumentation and the various installed monitoring devices. By questioning the trainee regarding the validity and meaning of the tests and calibrations performed during this checkout, an excellent knowledge of the instrumentation and control systems of the reactor is developed. After the checkout is completed, the trainee starts the reactor and attains criticality. The trainee is then instructed to operate the reactor in one of its several modes of operation such as steady state (manual or automatic), pulse, or square wave. The reactor is then shutdown and the session may be concluded with a question and answer period.

B. Observation of Reactor Operations

In addition to the two hours of reactor operation, an additional two hours of observation are scheduled for each trainee every week. Since there are many different types of experiments which are run using the

reactor, requiring various operating procedures, the trainee is brought into direct contact with these procedures and the possible problems associated with the use of the reactor for experimental work. During this observation period, the trainee may question the procedures being used and learn their derivation and meaning. The trainee also observes the roles and areas of responsibility of the reactor operator and the shift supervisor under actual operating conditions.

C. Classroom Lectures

Two hours per week are scheduled for classroom lectures. During the fall term this lecture series is basically concerned with health physics as it applies to reactor operation. The general areas covered are an introduction and definition of terms, detectors and monitors, radiation shielding, biological effects from exposure and emergency procedures, and regulations regarding waste disposal. The second lecture series, convening in the winter term, includes pulse characteristics, reactivity and poisoning calculations, physical characteristics of the plant, technical specifications, rod drive mechanisms, servo systems and safety analysis. Both lecture series include homework problems, quizzes and a final examination.

Upon completion of Reactor Operator Training the average trainee has completed a workload similar to that shown in Table 1 according to records maintained by the Nuclear Reactor Facility Training Staff.

TABLE 1. AVERAGE REACTOR OPERATOR TRAINEE WORKLOAD

Number of Reactor Checkouts	20
Number of Reactor Start Ups	26
Number of Reactor Shutdowns	15
Duty Hours (Operation and Observation)	60
Lecture Hours	40

Those trainees desiring an AEC Reactor Operator License are now eligible to apply for examination by the AEC providing they have passed mock examinations administered by the reactor staff. Considering those trainees who have completed Reactor Operator Training and applied for examination within the past six years, approximately 90% have successfully passed in examination and been granted a license.[10] This attests to the excellent caliber of instruction and training available through this program.

The learning objectives satisfied by Reactor Operator Training, excluding those previously satisfied by current courses, are radiation shipments and operator qualification. Thus, five objectives remain unsatisfied, including the additional work required to satisfy the safety analysis objective. These five areas should then comprise the basic course content of Supervisor Training.

VI. SUPERVISOR TRAINING

The optimum method of scheduling this program would require that no other credit courses could be scheduled by the participants of the program during the summer term. Unfortunately, this is not practical for two reasons: (1) other than those CEC officers required to participate in the program, student enrollment would be minimal; and (2) the nuclear instrumentation course offered in the summer term satisfies a learning objective and should be scheduled by CEC officers. In order to achieve an optimum schedule, a summary of the subject matter to be covered is in order. The areas of study include fluid flow, basic electronics, safety analysis, standard reactor tests, and fuel management. These five study areas may be presented by three types of instruction; tutored self-study, reactor tests and experiments, and classroom lectures.

A. Tutored Self-study

The study of fluid flow and basic electronics must be placed under this category. While general courses of study for these topics are available outside of the Nuclear Engineering Department, there is not enough time in the other five terms for them to be scheduled. Therefore, attaining a general knowledge of the detailed subject areas described in the learning objectives as they apply to pressurized water reactors must rest principally with the student. Until such time as current courses address the subject of thermoelectric material as applied to radioisotope thermal generator and the possible radiation damage of these materials, these topics should also be studied under this category. These topics are included in the learning objectives since it appears that

these power generators may become an important item of Navy portable shore power in the near future. Assistance in the pursuit of these studies might be provided by the Nuclear Engineering Department in the form of suggested source material, texts and/or publications, and assignment or recommendation of a professor or technician knowledgable in the topic under study who could advise and tutor the student in his studies. It is recognized that the student will be solely responsible for the satisfactory completion of these studies and that he alone is responsible for the success or failure of this endeavor.

B. Reactor Tests and Experiments

1. General - While certain basic experiments were performed in the Nuc E 502 laboratory series, several important experiments which are listed in the learning objectives were not included. During this portion of the program, the student will perform an experiment in which the characteristics and response of various types of power reactor instrumentation are observed. In the second experiment the student will determine the proper procedure for and perform excess reactivity measurements and apply the results to fuel accountability techniques. The third experiment will provide an opportunity for the student to observe the effects of phenonmenon such as Xenon production, peaking, and burnout.

The performance of these experiments differs from those previously performed in the 502 series in that the students are required to plan in detail and outline a step-by-step procedure for the experiment prior to performing the experiment. The written procedure and written report of the results should be representative of a highly professional product.

Each student will be afforded the opportunity to direct and coordinate the actual performance of an experiment under the supervision of the experiment director. He will be held responsible for the collection of appropriate data and termination of the experiment. Informal lectures on procedures and precautions will be provided by the experiment director.

2. Summary of Experiments and Investigations

a. Power Reactor Instrumentation

There are many varieties of detectors used in nuclear instrumentation for power reactor operation and safety circuits. Two of the more popular types of detectors are the fission chamber and the compensated ionization chamber. This experiment is designed to provide a thorough knowledge of the operational characteristics and possible deployment of such instruments in a power reactor. The student shall devise experiments using a gamma source or the reactor core, as appropriate, to determine the operational characteristics of these instruments and compare these results to the manufacturer's specifications and installed reactor instrumentation. Calibration of the fission chamber and compensation and calibration of the CIC will be performed. Detector response to different locations in and around the core and its response to various control rod configurations will be observed and compared to the expected response previously determined by the student. Finally a Cambelling system will be installed to the detector to obtain wide power range coverage using an ionization chamber. Advantages and disadvantages of the system will be discussed and observed: advantages such as excellent gamma discrimination and low extraneous noise; disadvantages such as pick up of an induced AC signal within the bandwidth.

b. Excess Reactivity Measurements and Fuel Accountability

An accurate record of the reactivity of a core over its

lifetime is mandatory for effective utilization and management of the fuel. In this experiment the students will add fuel elements to the periphery of the basic core and excess reactivity will be measured by the Inhour Method as each pair of fuel elements is added, using two types of rod positioning techniques. The results will be compared with each other and with computer calculations performed by the students. The different reactivity worths of similar fuel rods positioned at slightly different locations in the core will also be observed.

c. Xenon Transient Investigation

The effect of Xenon production, decay, and burnout on the reactivity of the core will be observed. Measurements and computer calculations performed in previous investigations of fuel burnup permit the investigation of the effect of Xenon buildup, decay and burnup during a long term high power operation, subsequent shutdown, and start up. Computer calculations will be performed by the students to compare with the measured results. The TR-48 analog computer will be programmed and operated by the students to initially predict the expected results and finally to simulate the measured results.

C. Classroom Investigation

1. Safety Analysis - The major portion of this part of the program shall be devoted to safety analysis. The most practical method of instruction for these lectures would utilize a current Preliminary Safety Analysis Report (PSAR) for a pressurized water reactor as a guide. Familiarization with the reactor system chosen would be accomplished by devoting the first eight or nine lectures to a study of the general description and/or performance objectives of the features described in each major

section and first sub-section of the PSAR. These familiarization lectures would place special emphasis on emergency safety features, and auxiliary and emergency systems. Once the student has become familiar with the various reactor features, the safety analysis section of the PSAR would be presented in detail. An estimated fifteen lectures should be devoted to this study. The accidents or events which should be presented in this study would include the following:

a. Uncompensated operating reactivity changes
b. Start up accident
c. Rod withdrawal accident at rated power operation
d. Moderator dilution accident
e. Cold water accident
f. Loss of coolant flow
g. Stuck-out, stuck-in, dropped-in control rod
h. Loss of electric power
i. Steam line failure
j. Steam generator tube failures
k. Fuel handling accident
l. Rod ejection accident
m. Loss of coolant accident
n. Maximum hypothetical accident.

Discussion of each of the above events should include an identification of the cause or identification of the accident, methods of analysis, and results of analysis.

2. Fuel Management - The second part of this section is devoted to a general survey of fuel management practices. Approximately six lectures would be devoted to a broad presentation of general fuel management areas such as in-core fuel management, intrinsic value of spent fuel, fabrication, enrichment and reprocessing.

D. Other Applicable Training

1. Conduct surveys for surface contamination in reactor buildings and laboratories.

2. Measure radioactivity in air in the reactor bay and identify isotopes producing it.

3. Measure radioactivity in reactor pool water and identify principle isotopes. Compare results to activity in nearby streams. Perform measurements of the reactor coolant water to determine its pH and conductivity.

4. Service conventional survey instruments such as G-M counter, "cutie pie" counter, and fast neutron counters.

5. Survey a reactor beam tube experiment to evaluate beta-gamma levels, and fast and thermal neutron flux.

6. Work with Health Physicist in supervising the disposal of solid radioactive wastes using G-M and fission product monitrons.

7. Operate evaporator to dispose of liquid wastes. Measure activity of feed and distillate water.

8. Assist in the performance of a regeneration cycle of the main stream demineralizer.

9. Supervise and participate in the decontamination of a simulated spill of radioactive material. Assist the Health Physicist in surveying

the area for the adequacy of the decontamination procedure.

With the general outline of this program completed, the only remaining consideration is that of determining a schedule which would allow completion of the described training in the ten week summer term. Consideration must be given to the fact that during this term, the student must near completion of the first draft of his engineering paper or thesis for December graduation. It appears that the classroom investigation and the practical training could be completed by scheduling four hours on Monday, Wednesday and Friday mornings. The reactor tests and experiments would then be conducted on Tuesday and Thursday mornings. This would provide ample time for the completion of all aspects of this study including the required written reports. The tutored self-study portion of the program would be conducted by appointment at the convenience of the tutor.

Now that the entire education and training package at The Pennsylvania State University for CEC Curriculum 572 has been developed, a general summary of the training programs developed by reactor vendors and the U.S. Navy (not including the Civil Engineer Corps) will be presented.

VII. TRAINING PROGRAMS DEVELOPED BY REACTOR VENDORS AND THE U.S. NAVY (OTHER THAN CEC)

Each of the five major nuclear reactor vendors has developed one or more training programs which it offers to the purchasers of its reactor systems. The U.S. Navy has developed a complete curriculum for use at the U.S. Naval Nuclear Power Schools which train Navy personnel for operation of shipboard reactor systems. A general description of each of these programs is given below.

A. Babcock and Wilcox Company [11,12]

While this company offers training programs at the management, plant operations and technical level, the plant operations level is of primary concern. There are five courses offered on this level: Nuclear Theory; PWR Observation; PWR Technology; PWR Operation; On-the-Job Training.

1. Nuclear Theory (12-16 Weeks) is directed at operators, operator supervisors and allied personnel. It is intended to provide basic theory in nuclear engineering including reactor theory. It is patterned to fit trainees with mixed educational backgrounds.

2. PWR Observation (3-5 Months) provides personnel observation of a PWR power plant for familiarization. This training is located at an operating PWR power plant.

3. PWR Technology (6 Weeks) is primarily for operating supervisory personnel. It is designed to give background on theory and PWR Technology as applied to a particular plant.

4. PWR Operation (12 Weeks) is primarily for reactor operators. It consists of operation training using the Babcock and Wilcox PWR Simulator

and Lynchburg Pool Reactor. It is intended to give operation experience needed for qualification as a reactor operator of a PWR.

5. On-The-Job Training (10 Months) gives all nuclear plant personnel intensive operator qualifications, equipment familiarization and procedural training on actual plant equipment. It includes a review of applicable theory and system-design information.

B. Combustion Engineering, Incorporated [12]

This company offers a reactor operator training program to give utility operating personnel academic knowledge plus practical experience needed to operate a nuclear reactor system in a safe and efficient manner. Courses offered include: Basic Nuclear Training; Observation Training and Reactor Simulator Operations; Nuclear Supply System (NSSS) Design Lecture Series; On-Site Training.

1. Basic Nuclear Training Course (14 Weeks) consists of academic work at a university with a research reactor available for experimentation and criticality practice. A minimum of ten reactor start ups and shutdowns are performed by each trainee . Reactor experiments demonstrating basic concepts are performed which relate the academic program to a practical understanding of reactor behavior.[a]

2. Observation Training and Reactor Simulator Operations (6 Months) combine two training phases. Approximately four months is allotted for Observation Training with a crew of an operating power reactor and two months concurrent for Simulator Operations.

[a] This course will be conducted by contractural agreement by The Pennsylvania State University commencing in 1971.

3. NSSS Design Lecture Series (6 Weeks) indoctrinates utility personnel in the design and operations of the NSSS.

4. On-Site Training (6 Months) includes one month of assistance for review training of personnel for AEC Cold Senior Reactor License Exams. Comprehensive written and oral exams are administered to each trainee.

C. General Electric Company [12]

This company offers a nuclear power plant training program which is divided into five parts. Since specialist training courses are part of the overall program, G.E. has developed a typical training schedule for the specific position to be held by the trainee. The following description represents the typical training program for the position of plant superintendent. [13]

1. Basic Nuclear Course (12 Weeks) is an introduction of nuclear phenomena as applied to reactor technology. Previous nuclear experience is not necessary.

2. Observation at Operating Reactor (12-16 Weeks) gives selected utility personnel background and familiarity with an operating nuclear power plant, plus radiation protection techniques. G.E. assists buyer in seeking this type of training arrangement.

3. BWR Technology (4 Weeks) deals with specific features of a BWR Plant, as well as with general considerations of reactor system design.

4. Operator Training at the General Electric BWR Training Center (12 Weeks) consist of control room exercises on the simulator, video taped lectures, and systems study inside the Dresden Station. This

well rounded program gives the operator in-plant experience concurrent with control room experience.[14]

5. On-Site Training (12 Months) includes a three month plant familiarization period coupled with operating and maintenance procedure writing and giving training to senior members of the plant staff, a six month pre-operational testing of equipment and checkout of plant operating procedures, and initial fuel loading, startup and power testing programs. This portion of the program is supervised by G.E. site engineers.

6. Specialist Training Courses are available in such areas as station fuel management, control and instrumentation, radiochemistry and radiation protection.

D. Gulf General Atomic Incorporated[12]

This company offers a five category training phase to prepare utility personnel for operation of High Temperature Gas-cooled Reactors (HTGR).

1. Basic Nuclear Indoctrination allows the trainee to assimilate and utilize all future training.

2. HTGR Operation Training aims at trainees becoming Senior Licensed Operators on an HTGR operating plant.

3. HTGR Tech Training gives prospective HTGR plant operators plus selected engineers, detailed, operationally oriented information on design, expected operating characteristics and scientific technology related to their own plant.

4. On-Site Training provides necessary work experience for all personnel assigned to the HTGR.

5. Specialist Training allows selected personnel to be trained in support areas directly related to their positions in plant staffing.

This training includes computer programming and maintenance, control and instrumentation, health physics and radiochemistry.

E. Westinghouse Electric Corporation [12]

This company's nuclear training program is intended to provide thorough PWR knowledge, operating ability and operating experience to nuclear power station personnel. The program is divided into four categories, two of which deal with replacement training and proficiency training which will not be discussed.

1. Initial Reactor Operator Training is designed for individuals with no background in nuclear power plant operation. The program consists of six phases.

a. Fundamental Training and Reactor Operations is conducted to provide the necessary knowledge for licensing as a senior operator.

b. Fundamental and Initial Plant Systems and Operations Training is conducted on the operator level at the plant site.

c. Westinghouse Atomic Power Division (WAPD) Lecture Series is intended to provide information on design and operation of systems and components of the specific plant the trainee will operate.

d. Observation Period is held at an operating PWR for key personnel and shift supervisors.

e. Plant Systems and Operations is conducted at the plant site for key personnel.

f. Examination Preparation and AEC Examination provides a comprehensive review at the plant site.

2. Additional Training Programs:

a. Nuclear and PWR Technology

b. Special Design Lecture Series

c. Specialist Training

d. Instrument Technician Training

e. Health Physics Technician Training

f. Basis Physics and Mathematics Refreshers.

F. U.S. Naval Nuclear Power Schools

The program at these schools is divided into two categories. The first six months is spent in classroom lectures and the second six months consist of prototype training.

1. Officers Course

a. Mathematics (Equivalent to two terms) includes fundamental concepts, ordinary and partial differential equations, and Bessel functions.

b. Physics (Equivalent to 3-1/2 terms) includes classical, atomic and modern, and nuclear physics; nuclear reactor theory and the nuclear reactor.

c. Electrical Engineering (Equivalent to 2-1/2 terms) includes the basic aspects of electrical theory, electrical machinery, electronics, magnetic amplifiers and control systems.

d. Heat Transfer and Fluid Flow (Equivalent to 2 terms) consists of engineering thermodynamics, fluid mechanics, heat transfer and reactor core analysis.

e. Chemistry (Equivalent to 1 term) provides basic concepts necessary for understanding water chemistry control.

f. Radiological Fundamentals and Radiation Shielding (Equivalent to 1 term) includes definitions, types of radiation and exposure control,

biological effects, various radioactive sources, principles of detection and shielding.

g. Materials (Equivalent to 1 term) includes elements of physical metallurgy, strength of materials, metal forming and joining, corrosion and irradiation, and various types of materials used in a nuclear reactor.

h. Power Plant Characteristics (Equivalent to 1 term) includes fundamentals of reactor kinetics, dynamic reactor behavior and control, and reactor plant behavior in sub-power and power range operation.

i. Core Characteristics (Equivalent to 1-1/2 terms) is designed to teach the interrelations between nuclear and thermal-hydraulic aspects of a PWR.

j. Aspects of Reactor Plant Operation (Equivalent to 1 term) brings together the basic principles and theory developed in previous courses and relates them to problems associated with the operations of naval reactors.

2. Prototype Training Program

a. Classroom Phase (approximately 3-1/2 months) consists of lecture series, special training, and oral and written examinations.

b. In-Plant Phase (approximately 2-1/2 months) consists of watchstanding, written and oral examinations, system checkout, qualification, and final oral checkout.

In summary, it is clearly evident that the education and training program outlined in this paper covers all categories of training offered in the programs described above with the exception of on-site or prototype training. Since no major university has a power producing pressurized water nuclear reactor system as a part of its facilities, this

necessary training phase must be accomplished after the completion of Curriculum 572 and should not be considered a part of this curriculum. In fact, this training is available to CEC officers in the form of three programs of instruction offered by the U.S. Army Engineer Reactors Group, Fort Belvoir, Virginia. Each officer assigned to the Navy Nuclear Power Unit is enrolled in the seven week Nuclear Plant Engineer Course. This course principally provides general power plant information, simulator operations, nuclear power plant operations and concurrent training, and a review of nuclear reactor engineering and radiation safety.[15] Officers chosen as a prospective Officer-in-Charge, PM-3A, McMurdo Station, Antarctica are enrolled in two additional programs of instruction. The Nuclear Power Plant Officer-in-Charge Course (6 weeks) is intended to provide a thorough "...understanding of all aspects of nuclear power plant theory, development, operation, administration, and maintenance".[16] The PM-3A Replacement Crew Training Course (8 weeks) is intended "To familiarize the student with: the design features and operating characteristics of plant systems and subsystems; safety procedures and the functioning of safety and protective systems; operating procedures and limitations; emergency procedures; and environmental conditions for the PM-3A Nuclear Power Plant at McMurdo Station, Antarctica".[17] The course also provides "Specific preparation of the student for qualification as PM-3A Naval Nuclear Power Plant Operator".[17]

VIII. SELECTION OF CANDIDATES AND EDUCATIONAL INSTITUTION

A. Selection of Candidates

There are several major considerations which must be made during the officer selection process for this particular curriculum.

Of primary concern is the officer's motivation for pursuing an education and a career in nuclear engineering. The mode of thought which underlies science and technology has been characterized by: a longing to know and understand; questioning of all things; searching for data and their meaning; a demand for verification; a respect for logic; consideration of premises; and consideration of consequences.[18] None of these factors are stimulated without a basic desire to pursue the chosen field of endeavor, in this case nuclear engineering.

Secondly, the officer's performance as an undergraduate must be scrutinized very carefully, especially if this work was not performed in the nuclear field. Merely setting an overall standard, such as requiring a final average of "B" or better for undergraduate work is not enough. Areas of study which are basic to nuclear engineering such as physics, differential equations, heat transfer and other basic topics listed in the learning objectives developed in this paper should be chosen as indicators of the officer's ability to do satisfactory graduate work in this field. Evaluation of the officer's performance while in the Navy is also important. This information is available to the selection board in the form of evaluation reports submitted periodically by superior officers.

Finally, the discipline in which the officer completed his undergraduate study must be considered. The most suitable background would

be that of nuclear engineering, but there are very few, if any, officers with a bachelors degree in nuclear engineering in the Navy Civil Engineer Corps who become eligible for selection. It is, therefore, necessary to select candidates with degrees in other engineering disciplines. Since we are principally concerned with power systems and power distribution it would appear that officers with degrees in mechanical or electrical engineering would be best suited for this curriculum. Reviewing the list of learning objective previously presented, one finds a preponderance of subject matter related to these two disciplines. Another indicator which may be used is the number of mechanical and electrical engineers employed in the Atomic Energy field as opposed to the number of civil engineers. (The choice of civil engineers here was made since most Civil Engineer Corps officers hold a bachelor degree in civil engineering as have the past six selectees to this curriculum). The Bureau of Labor Statistics Report 333, Employment Characteristics of Atomic Energy Work, 1967, shows that the ratio of mechanical to civil and electrical and electronic to civil engineers in the industry is seven to one and six to one respectively. It appears that an officer with a mechanical engineering degree would be best suited for advance study in nuclear engineering, closely followed by one holding a degree in electrical engineering.

In summary, the ideal candidate for this curriculum would be: (1) highly motivated toward a career in nuclear engineering; (2) well versed in the basic aspects of physics, differential equations, and heat transfer; and (3) hold a bachelor degree in nuclear, mechanical or electrical engineering.

B. Selection of the Education Institution

"In 1968, there were approximately sixty schools in the United States with Graduate Programs in Nuclear Engineering...".[2] While there are many factors which should be investigated in selecting an education institution with a Nuclear Engineering Department at which the previously listed objectives could be satisfied, those discussed here shall include: (1) the facilities available for graduate studies; (2) faculty to student ratio and variety of course offerings; and (3) orientation and flexibility of the Nuclear Engineering Department.

Some of the major facilities required to support the curriculum and graduate level research are: an operating research reactor rated at one Megawatt or greater; a subcritical pile; a large Cobalt-60 source for massive gamma radiation; multichannel analyzers; hot cells; a pulsed neutron source; an analog computer with the capacity of TR-48; and use of a digital computer. Furthermore, the university should be located close enough to operating nuclear power plants (preferably of different types) so that one-day comprehensive field trips are feasible.

The faculty to student ratio and variety of courses offered are important factors which weigh heavily in satisfying the described curriculum. Since most of the officers selected for this program have no nuclear background it is particularly desirable to select a university with a Nuclear Engineering Department which has the capacity to offer considerable individual attention to its graduate students. A variety of course offerings would naturally ease the task of fulfilling the established learning objectives of this curriculum.

Since this curriculum is oriented toward power production, it is essential that the Nuclear Engineering Department at the chosen university

be power oriented. Innovations in the design, control and operation of nuclear power systems are being applied to new systems in ever increasing numbers. Only a faculty with deep interests in this field could remain appraised of the latest system concepts and only a department offering a flexible curriculum could present these concepts to the student as they are installed and tested in the field.

The Nuclear Engineering Department at The Pennsylvania State University satisfies all of the criteria described above. PSU is currently the only university listed for Curriculum 572 (CEC) by the U.S. Navy and there appears to be no reason to change this selection in the near future. Therefore, the curriculum proposal for Nuclear Power Engineering, Curriculum 572, for U.S. Navy Civil Engineer Corps Officers is developed for implementation at The Pennsylvania State University.

IX. CURRICULUM PROPOSAL FOR NUCLEAR POWER ENGINEERING, CURRICULUM 572 (CEC)

The curriculum shown in Table 2, was developed for implementation at The Pennsylvania State University. It is arranged so that the previously listed learning objectives will be satisfied in an eighteen month period commencing with the summer term. The curriculum is designed for an officer with the background and motivations discussed in Section VIII.A. While it is expected that specific course content will vary from year to year, it is expected that the general objectives of each course listed will remain unchanged and thereby satisfy the learning objectives previously listed.

TABLE 2. PROPOSED CURRICULUM 572 (CEC)

FIRST SUMMER TERM
- Differential Equations (MATH 100)
- Introduction to Atomic and Nuclear Physics (PHYS 237)
- Principles of Programing with Physical Science Applications (CMPSC 401)
- Nuclear Engineering Special Topics (NucE 400)

FIRST FALL TERM
- Nuclear Engineering (NucE 410)
- Reactor Engineering Laboratory (NucE 502A)
- Heat Transfer (ME 412)
- Reactor Operator Training (Part I)

WINTER TERM
- Nuclear Engineering (NucE 411)
- Reactor Engineering Laboratory (NucE 502B)
- Design Principles of Reactor Systems (NucE 430)
- Reactor Operator Training (Part II)

SPRING TERM
- Design Principles of Reactor Systems (NucE 431)
  or
  Reactor Engineering (NucE 501)
- Reactor Engineering Laboratory (NucE 502C)
- Reactor Control (NucE 505)
- Electronic Analog Computers (EE 470)

SECOND SUMMER TERM
- Reactor Instrumentation (NucE 550)
- Supervisor Training
- Thesis or Engineering Paper (NucE 600 or NucE 500)

SECOND FALL TERM
- Nuclear Reactor Materials (NucE 511)
- Radiation Shielding (NucE 508)
- Thesis or Engineering Paper (NucE 600 or NucE 500)

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